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MEASURED SETTLEMENTS OF THE PESNICA HIGH EMBANKMENT

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Abstract: A detailed study has been performed of the settlements which occurred in the subsoil beneath the Pesnica high embankment, which was built as part of Slovenia's National Motorway Construction Programme. This embankment had to be built on very compressible subsoil of low bearing capacity and low permeability. Two measurement methods, using conventional settlement plates, and a hydrostatic profile gauge which could be placed in specially installed measuring tubes, were used to obtain settlement profiles at several locations along the embankment. The results showed that the development of subsoil settlements at two selected locations was very different, due to the heterogeneity and varying compressibility of the subsoil. The settlements obtained by measurements using the hydrostatic profile gauge were very similar to those obtained using settlement plates which were located close to the measuring tubes.

1. INTRODUCTION

As a part of the National Motorway Construction Programme, a large number of high embankments founded on soft soil have been built in Slovenia. One of them, the Pesnica high embankment, is located on the motorway section Šentilj – Pesnica, close to the city of Maribor (see Figure 1).

The Šentilj – Pesnica motorway section

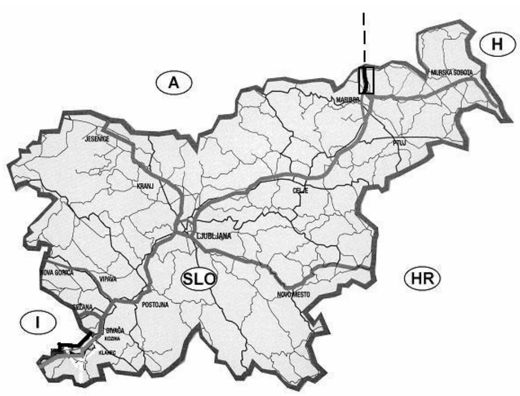

Figure 1 - The planned motorway network in Slovenia

The height of the embankment varies between 6.0 and 8.0 m. The embankment had to be built on very compressible subsoil, with a low bearing capacity and low permeability, so it was necessary, in the design, to provide adequate measures to increase the stability and consolidation rate of this subsoil. After several geotechnical studies of the predicted performance of the embankment had been performed, stone columns were chosen to reinforce the soft subsoil. A system for geotechnical monitoring of the embankment and the subsoil beneath it, whose aim was to monitor the performance of the embankment, was established.

2. GEOTECHNICAL CONDITIONS

The investigations showed that the subsoil beneath the planned Pesnica embankment, described from the top downwards, consisted of the following layers:

- a 3.0 to 4.5 m thick layer of firm brown to grey clay, of high plasticity,
- a 3.0 to 4.5 m thick layer of grey to black sandy to silty clay, with layers of organic clay (this was the critical soil layer with regard to bearing capacity and deformability),
- a 1.0 to 1.5 m thick layer of clayey silt, with layers of sand,
- a 0.5 m thick layer of grey weathered marl,
- grey marl bedrock.

The total thickness of the three top layers of compressible cohesive subsoil was about 8.5 to 9.0 m.

3. SETTLEMENT MEASUREMENTS

As part of the system for geotechnical monitoring of the embankment, measurements of settlements were performed, using two methods, in order to obtain settlement profiles at various locations along the embankment. Besides conventional settlement plates, which were installed at numerous transverse profiles along the embankment, also two measuring tubes (designated HI-1 and HI-2) were installed at two of the measuring cross-sections.

3.1. Locations of the settlement plates and measuring tubes

The measuring tubes HI-1 and HI-2 passed very close to the corresponding settlement plates PL-1 to PL-4 and PL-8 to PL-11, although they were about 0.5 m higher than these plates (for their locations, see Figures 2 and 3).

The measuring tube HI-1 was located at the cross-section where the largest settlements were expected, whereas the measuring tube HI-2 was installed at one of the widest cross-sections of the embankment. The mouth of the measuring tube HI-1 was accessible only on one side of the embankment, so the settlement probe was pushed, with aluminium rods, through the tube. Since the mouth of the measuring tube HI-2 was accessible on both sides of the embankment, the settlement probe was pulled, with a draw-cord, through the tube. The measurement step was 1.0 m. The lengths of the two measuring tubes were 49 m (HI-1) and 85 m (HI-2). The tubes were installed in a 60 cm deep trench, which had been excavated when the embankment was 1.0 to 2.0 m high.

The reference pins for the hydrostatic profile gauge measurements were located on small concrete slabs, which were located at the mouths of the measuring tubes. They were just within the influence zones of the embankment, so geodetic measurements of the settlements of these pins were also performed.

Due to the fact that the measuring tubes and settlement plates were, for technical reasons, situated a little higher than the bottom of the embankments, the results do not show the exact settlements of the subsoil, but slightly smaller settlements.

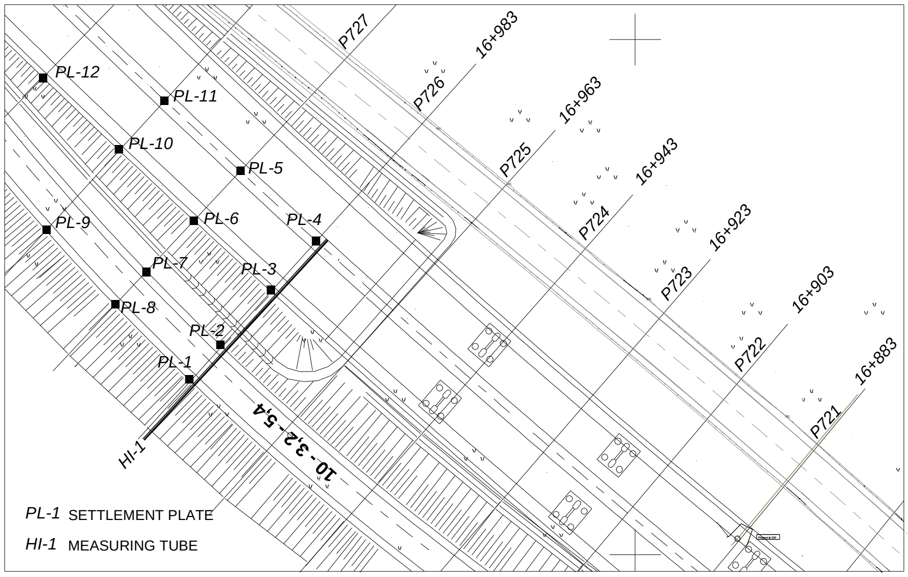

Figure 2 - The situation of the first section of the Pesnica embankment, showing the system for monitoring settlements

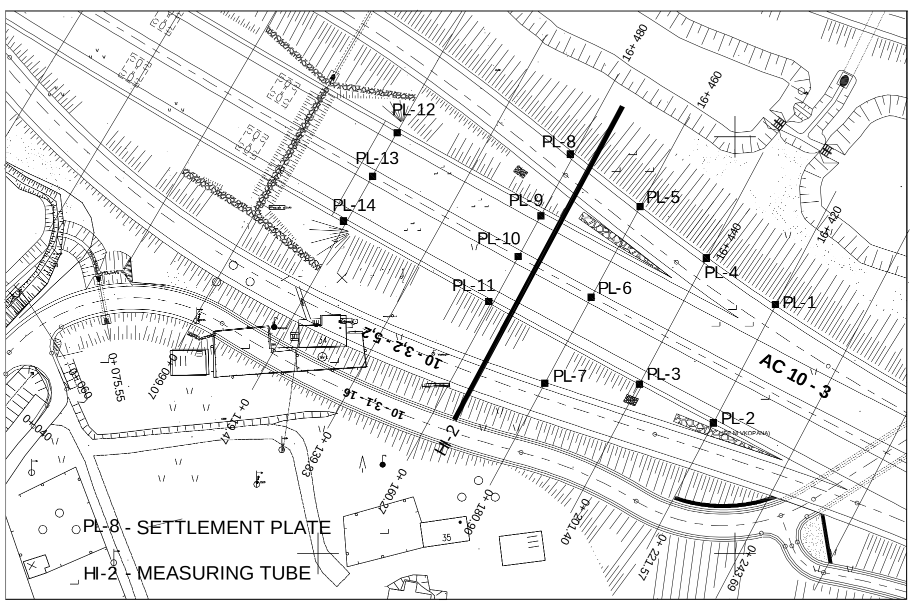

Figure 3 - The situation of the second section of the Pesnica embankment, showing the system for monitoring settlements

3.2. Operation of the hydrostatic profile gauge

A hydrostatic profile gauge is a device which can be used to measure the vertical displacement of structures such as road embankments and earth dams across the entire width of the structure. It consists of a control unit, a readout unit, and a length of triple tubing which is connected to a settlement probe that can be pushed (by means of aluminium rods) or pulled (with a draw-cord) through the measuring tube beneath the structure (see Figure 4).

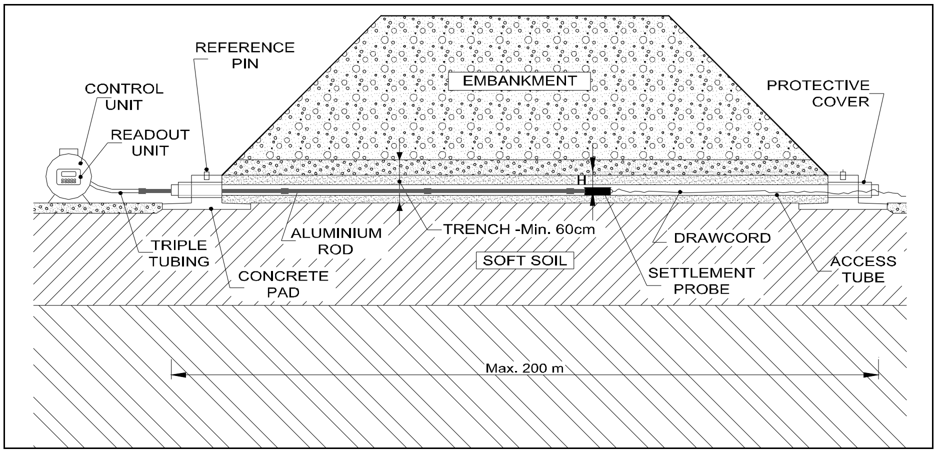

Figure 4 - General arrangement of a hydrostatic profile gauge being used beneath an embankment

Two of the three small tubes are filled with water and are constantly back-pressurized in order to overcome surface tension effects, and to prevent the formation of bubbles. Measurements of elevation are taken at regular intervals along the measuring tube, which is laid in a sand-filled trench before the start of embankment construction (see Figure 5). The hydrostatic head ‘H’ is measured by means of a differential pressure transducer. The readings are related to a reference pin outside the tube, and in this manner a complete elevation profile of the tube can be established. By comparing profiles taken at different times, the vertical displacement of the tube between any two readings can be determined to an accuracy of ± 1.0 cm, which is excellent for such applications.

Figure 5 - Installation of the measuring tube HI-2

4. RESULTS

4.1. Comparison of settlement development at two different profiles

The settlements of the embankment obtained by measurements performed using the HPG, at points 1.0 m apart, along the measuring tubes HI-1 and HI-2, are shown, for different heights of the embankment construction, in Figures 6 and 7. The reference measurement (settlement = 0) was performed in the middle of April 2004. The final contour of the embankment is also shown in these two figures. At the time of the reference measurement the height of the embankment was about 2.0 m (HI-1) and 1.0 m (HI-2), so that some subsoil settlement had already occurred.

In the case of profile HI-1, embankment construction from a height of 2.0 to 8.0 m caused a 3 cm settlement of the subsoil on the left hand side of the embankment (geodetic measurements) and a 43.5 cm subsoil settlement on the opposite side of the embankment (HPG measurements) (see Figure 6). It can be seen from this figure (the two lowest curves) that the completion of the embankment caused additional settlements mainly on the right hand side of the measuring cross-section.

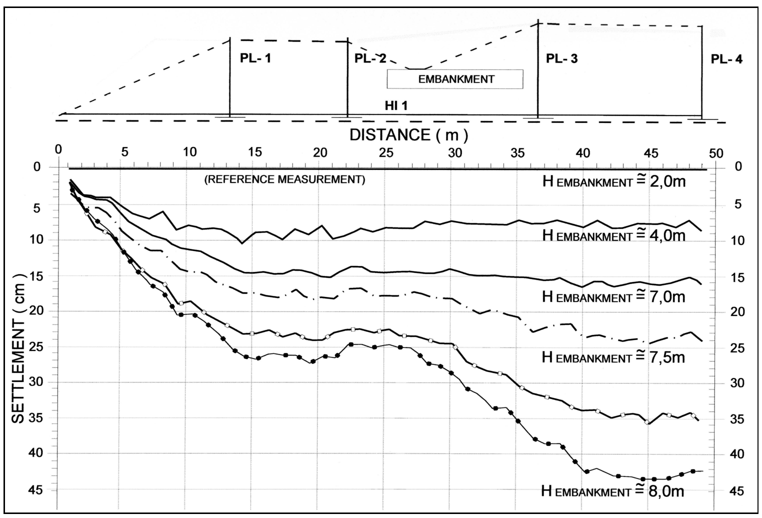

Figure 6 - Settlement profiles, at different heights of embankment construction, along measuring tube HI-1 (L = 49 m)

In the case of profile HI-2, embankment construction from a height of 1.0 to 7.5 m caused a 2 cm settlement of the subsoil on the left hand side of the embankment (geodetic measurements) and a 19 cm subsoil settlement under the higher part of the embankment (HPG measurements) (see Figure 7). It can be seen from this figure (the two lowest curves) that the completion of the embankment caused additional settlements mainly in the middle of the measuring cross-section.

It can be seen that the development of settlements at two selected profiles was very different, which is the consequence of the heterogeneity and different compressibility of the subsoil beneath the embankment at these two locations.

The last measurements of subsoil settlements were performed in December 2005 (i.e. one year after the embankment had been completed), just before the motorway was opened for the traffic. Further measurements were not performed because the monitoring project had been concluded.

The subsoil settlements obtained by deformation analyses, which were performed using the finite element method, assuming a Mohr-Coulomb material model, were very similar to those obtained using the field measurements.

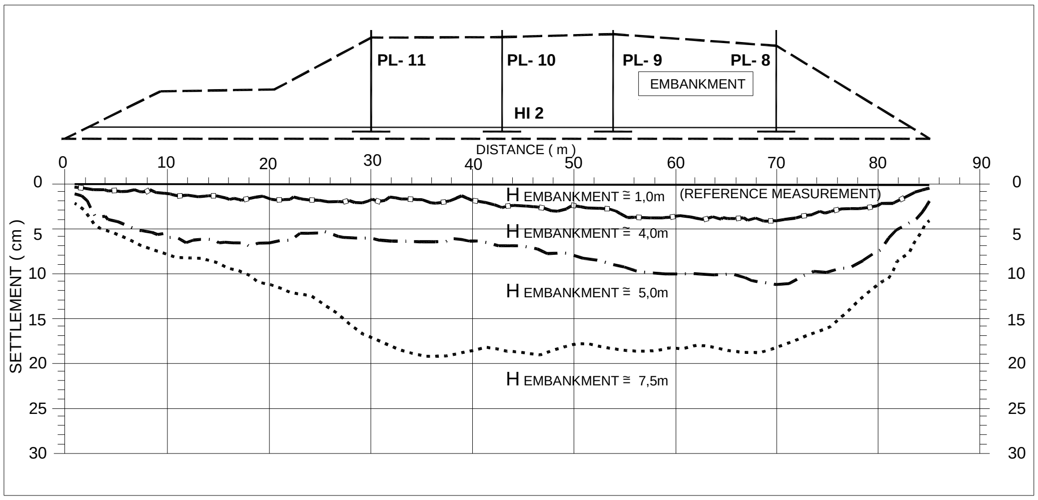

Figure 7 - Settlement profiles, at different heights of embankment construction, along measuring tube HI-2 (L = 85 m)

4.2. Comparison of settlement development using two different methods

Figures 8 to 10 show a comparison of the settlement development, measured in the measuring tubes HI-1 and HI-2, with the settlements observed on plates PL-3, PL-4 and PL-10, which were located very close to these measuring tubes, and the progress of the embankment construction at the locations of these three settlement plates. The reference measurement of the vertical displacements of the settlement plates was performed in the middle of February 2004 (the reference measurement in the tubes was performed two months later). For comparison of the results of these two methods, the soil settlement measured by optical levelling of the settlement plates up until April 2004 (up to 1.6 cm) was taken into account.

It was shown that the values of the settlements, as well as the settlement development measured by the HPG, were very similar to those observed on the settlement plates, which were located very close to the measuring tubes. At the time of the last measurements, in December 2005, the difference between the settlements obtained using the two different methods varied from 1.1 cm (at PL-10) to 3.3 cm (at PL-4); the settlements measured using the HPG varied from 19.3 cm (at PL-10) to 43.6 cm (at PL-4), whereas the maximum settlement measured using the settlement plates was 40.3 cm (PL-4). These differences may have arisen for a number of reasons, among which the most important are:

- the fact that the settlement plates PL-3, PL-4 and PL-10 were located close to the measuring tubes HI-1 and HI-2, but not at exactly the same location,
- the fact that the measuring tubes were located about 0.5 m higher than the settlement plates, so additional settlements because of subsidence of the embankment were obtained.

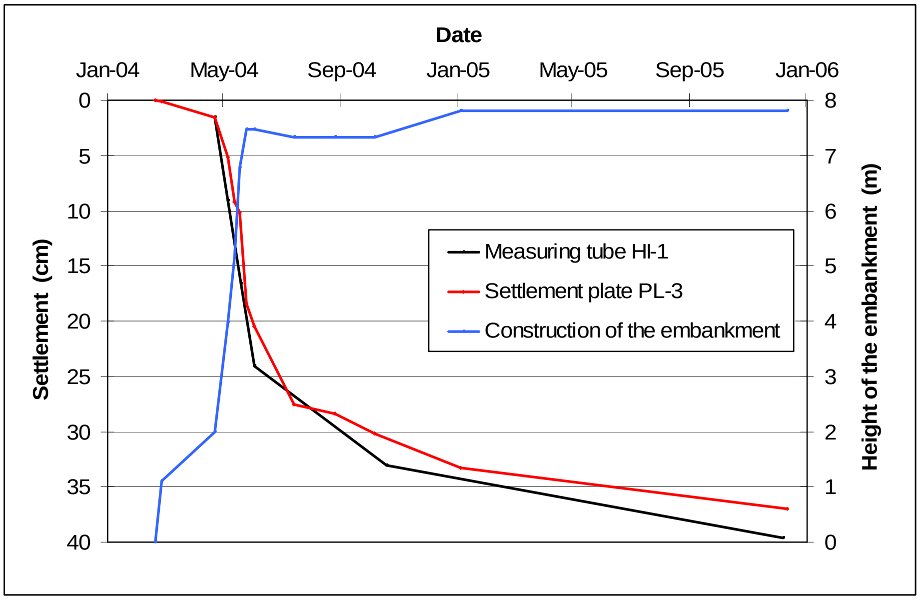

Figure 8 - Settlement development measured at the location of plate PL-3, using two different methods, compared with the progress of embankment construction

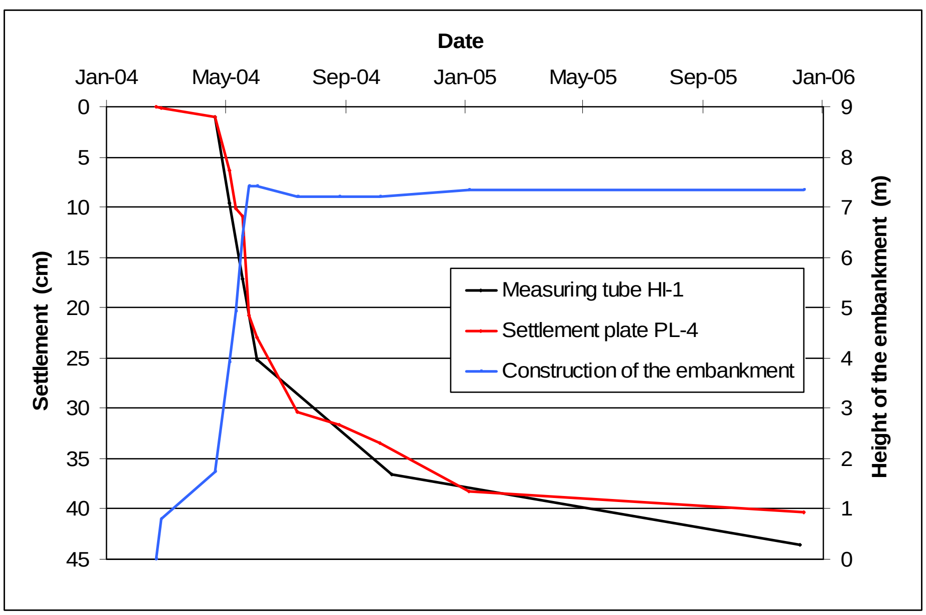

Figure 9 - Settlement development measured at the location of plate PL-4, using two different methods, compared with the progress of embankment construction

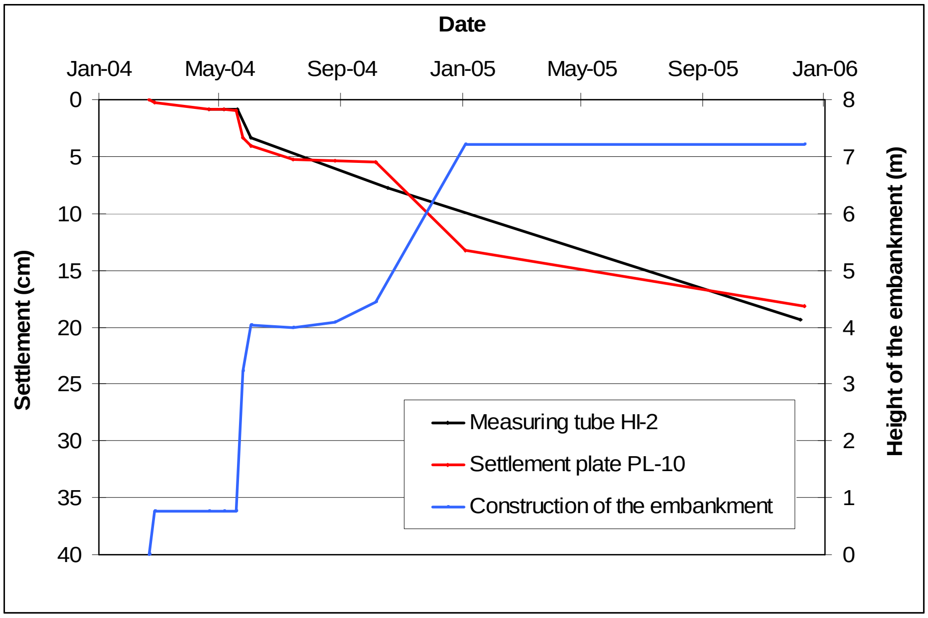

Figure 10 - Settlement development measured at the location of plate PL-10, using two different methods, compared with the progress of embankment construction

5. CONCLUSIONS

The use of a measuring tube and a HPG (the HPG has been in use in Slovenia since 2001), which do not interfere with construction works, has proved to be an excellent practical solution. The results consist of not just a single settlement (like that obtained when a settlement plate is used), but a complete settlement profile. Because of the relative values of the vertical displacements measured by the HPG, the absolute height of the reference pin at the mouth of the tube has to be determined by geodetic measurements. When analyzing settlements, and determining their absolute values, the progress of embankment construction before the reference measurement is made needs to be taken into account. When the mouth of the measuring tube is accessible on both sides of the embankment the settlement probe can be pulled through the tube with a draw-cord, which was performed in the case of the settlement measurements along the measuring tube HI-2. This work is much less time-consuming than when the probe has to be pushed through the tube with aluminium rods (as in the case of the settlement measurements along the measuring tube HI-1).

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